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THE CONTRIBUTION OF ASPHALT ROAD SURFACES TO FIRE RISK IN TUNNEL FIRES: PRELIMINARY FINDINGS

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ABSTRACT

Most fire experiments carried out in tunnels to date have focussed on the burning behaviour and smoke production of liquid pool fires and vehicle fires. Other combustible surfaces, commonly found in tunnels, have not been considered in detail. This paper presents the preliminary findings of a research project into the fire behaviour of asphalt road surfaces. Small samples of asphalt material have been studied using a Cone Calorimeter. Factors such as the critical heat flux for ignition and the heat release rate of these samples have been identified. These factors are discussed in relation to tunnel fires.

1. INTRODUCTION

Despite a number of experimental tunnel fire test series in recent years, there are still many aspects of tunnel fire safety which have not been adequately investigated to date. These experimental fire tests have generally concentrated on issues relating to the behaviour of smoke and the burning of vehicle and pool fires. However, other aspects of fires in tunnels are also of great interest.

One unanswered question with regard to tunnel fires concerns the involvement (if any) of asphalt pavement materials in tunnel fire incidents. Certainly, the behaviour of the asphalt pavement hindered the fire brigade in the Fréjus Tunnel fire incident (2005); the roadway melted 'under the feet' of the fire-fighters in the vicinity of the fire [1]. Large sections of asphalt roadway also burned away and had to be replaced following the fires in the Mont Blanc and St. Gotthard tunnels. What is not clear is when the asphalt pavement ignited and became involved in the fire during these incidents, or whether it contributed in any significant way to the severity of the fires.

Due to concerns about "the flammability of asphalt mixes", Austria has banned the use of asphalt roadways in all tunnels over 1km in length [2]. However, this decision appears to have been made primarily by expert judgement without any grounding in experimental observation.

Asphalt is a complex composite composed, in part, of organic bitumens. Despite the flammability of bitumens, neither the burning properties of bitumen or of composite asphalt have been adequately investigated to date. The only experimental study of the fire behaviour of asphalts was carried out by Noumowe in 2003 [3,4]. This study found that samples of typical road surface asphalts (when heated in a furnace programmed according to the ISO 834 temperature curve) ignited between 480 and 530°C. This caused the temperature in the oven to rise to 900°C, some 150° above the maximum programmed furnace temperature. Further investigation observed some degradation of the asphalt at temperatures as low as 300°C. Noumowe also investigated the toxicological properties of the combustion products of asphalt. These experiments followed the standard approach to testing of materials used in the construction industry. This approach is useful to assess material response to fire but is clearly not an adequate method for assessing material flammability or ignition conditions and, thus, is not able to provide sufficient data for Computational Fluid Dynamics (CFD) and other fire models.

A new research project has been started at Edinburgh University which aims to fully characterise the fire behaviour of typical asphalt road pavement materials. The conditions for ignition of and fire spread across a range of asphalt formulations will be assessed and the heat release rates of these materials will be measured. It is ultimately intended to incorporate these data into CFD models to enable accurate simulation of tunnel fire scenarios.

This paper presents the preliminary results for a typical asphalt formulation.

2. APPARATUS AND SAMPLES

The initial study of asphalt ignition and burning has been carried out using a cone calorimeter. This apparatus is used to study the fire behaviour of samples of material exposed to heat fluxes of up to about 75kW/m^2. The apparatus is described in detail elsewhere [5]. Samples of asphalt (100 × 100 × 60mm) have been tested using this apparatus at heat fluxes between 30 and 60kW/m^2. The recorded data includes the heat release rate (HRR) of the sample, amongst other factors.

The samples used in the initial study were provided by the Nottingham Centre for Pavement Studies at the University of Nottingham. These were composed of Stone Mastic Asphalt (SMA), which is currently the most popular bituminous road surfacing material in the UK. The bitumen content of the samples was 6.3% (by mass), the bitumen was graded as '40-60 pen'. The rest of the mix was composed of mineral aggregates up to about 20mm in size and some cellulose fibres (0.3% by mass). The compacted samples (prepared as if they were a roadway) had an air void content of about 6%.

3. RESULTS

The four samples of asphalt were exposed to external heat fluxes of 60, 50, 40 and 30 kW/m^2. In each test there was a period of a few minutes during which nothing visible occurred. After this initial heating phase a vapour began to be produced at the surface, this did not ignite (except in the case of the 50 kW/m^2 test, see below). After several further minutes of exposure to the heat flux, the 60, 50 and 40 kW/m^2 samples eventually ignited properly – that is, a luminous flame covered the surface of the sample. The 30 kW/m^2 sample did not ignite. Each of the ignited samples continued to burn for over an hour before burning out. The heat release rate data are presented graphically in Figure 1.

During 50 minutes of exposure to 30 kW/m^2, the fourth sample produced significant quantities of vapour, but this did not produce sustained burning. Occasional flashes of flame were observed, but these were not sustained. After 50 minutes the heat flux was increased to 35 kW/m^2, but no ignition occurred. After a further five minutes, the heat flux was increased to 40 kW/m^2 which lead to the sample igniting within two minutes.

The samples that did ignite exhibited two distinct phases in their burning:

(i) A period of fairly low heat release. In the 50 kW/m^2 test, there was a significant luminous flame during this phase, but this did not cover the entire surface of the sample. In the 40 and 60 kW/m^2 tests this was not accompanied by significant luminous flames, but there appeared to be a barely-luminous flame flickering near the centre of the sample.
(ii) A period of significantly higher heat release. Rising swiftly to the peak heat release rate. In this phase the flames covered the surface of the sample, see Figure 2.

These two phases can be clearly seen in Figure 1.

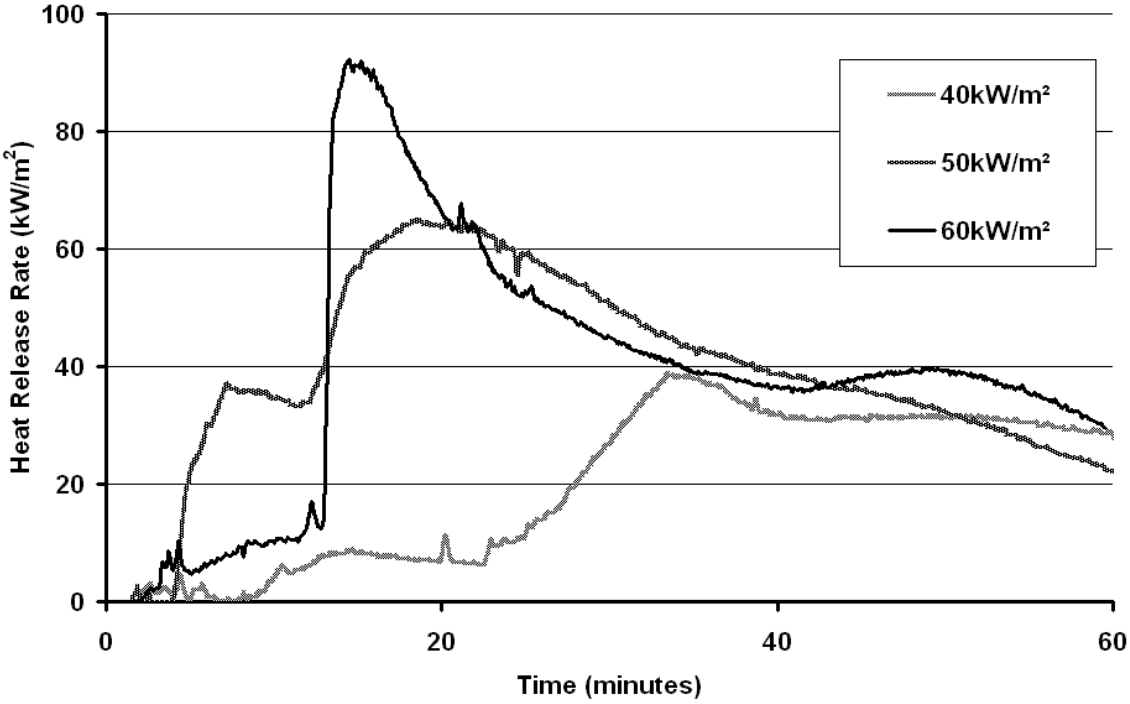

Figure 1 – Heat Release Rate graphs for the asphalt samples exposed to 60, 50 and 40 kW/m^2.

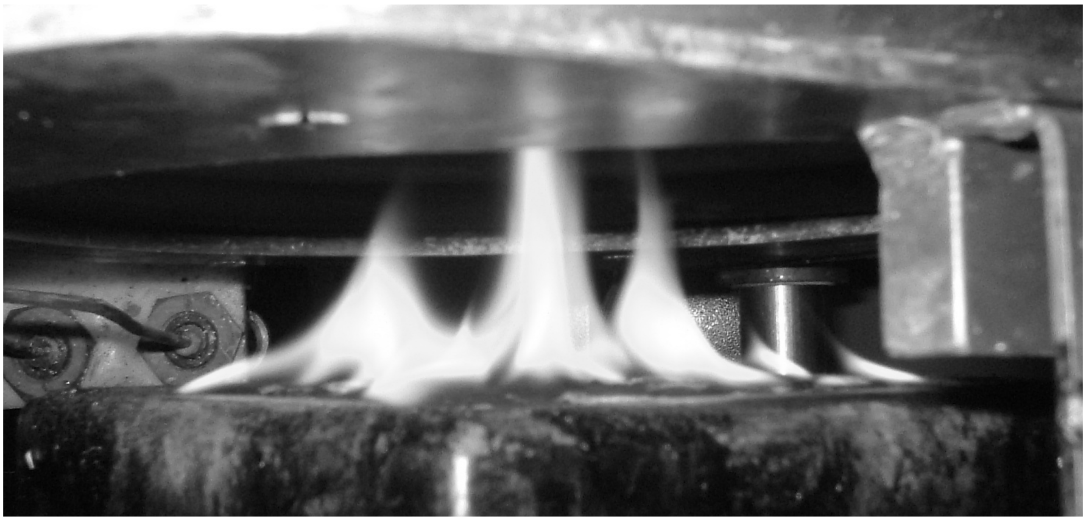

Figure 2 – Photograph of the asphalt burning (during the 40 kW/m^2 test).

Post-test sample observations

Figure 3 shows photographs of the asphalt samples before and after a test. The principal observations of the samples after the tests are:

(a) There are more visible voids within the sample, particularly near to the top face.
(b) There is an accumulation of bituminous material near to the lower face of the material.
(c) The structural properties of the material are destroyed during the test; the sides of the sample have bowed out slightly (despite being constrained by the sample holder) and the post-test material is crumbly and comparatively easy to break.

Figure 3 – The asphalt samples before and after a test.

4. DISCUSSION

From these preliminary tests it is clear that the critical heat flux for ignition of asphalt is smaller than 40kW/m^2. Heat fluxes of this magnitude are certainly produced in tunnel fire incidents and experiments.

During the fire tests in the Runehamar Tunnel in Norway in 2003 [6] heat fluxes were recorded at various locations near to the fire sources (simulated HGV trailers). In the first three tests (one loaded with wood & plastic pallets, the second loaded with wooden pallets & mattresses and the third loaded with furniture) this critical heat flux was exceeded at locations on the roadway, downstream of the fire location, where the maximum fluxes recorded were about 280, 200 and 75 kW/m^2, respectively. Heat fluxes above this critical limit were also recorded 5m upstream of the fire location in the first test, where the peak flux almost reached 100 kW/m^2 [7].

From this comparison it is clear that ignition of the asphalt roadway in the downstream vicinity of a HGV fire should be expected and upstream ignition of the roadway should not be discounted.

As noted above, the burning behaviour of the asphalt exhibits two distinct phases. The first, lower heat release, phase is believed to be the phase when the bituminous material on the surface burns. The second phase follows once the bulk material has heated sufficiently to melt and vaporise the binder bitumen. The molten bitumen tends to sink to the base of the sample (which is consistent with the post-test observations), but once the material starts to vaporise or volatilise, the vapours are forced upwards and ignite at the surface.

The 50 kW/m^2 test exhibited different burning behaviour from the other samples tested. Here, the initial vapours ignited early on in the test, although the flames remained localised near the middle of the sample. This anomalous behaviour is believed to be as a result of non-uniformity of the asphalt mix. In this instance it is thought that there was a larger layer of bitumen at the top surface of the sample which was sufficient to ignite before the bulk of the material had heated up to ignition conditions. The additional heating from this flame will also have brought the onset of phase (ii) ‘ignition’ earlier than would have been expected. This will be confirmed in future tests.

As demonstrated above, heat release rates of almost 100 kW/m^2 are produced with incident heat fluxes of the order of 60 kW/m^2. It is to be expected that higher incident fluxes will produce higher heat release rates. Even if asphalt ignition is limited to the area immediately downstream of a HGV fire, this may still involve an area of roadway greater than 50m^2, so the heat release rate due to the asphalt may be 5MW or greater, which is equivalent to at least one or two car fires. In severe cases, the asphalt under the vehicle, adjacent to it and upstream of it may become involved as well, potentially resulting in heat release rates above 20 MW – as a direct consequence of the asphalt.

5. CONCLUSIONS AND FUTURE WORK

A series of preliminary tests have been conducted with typical asphalt samples. The experiments point towards two important conclusions:

- Typical asphalt mixtures have the potential to ignite during tunnel fires and produce heat release rates comparable to that of other fuel sources commonly found in tunnels (e.g. cars).
- Ignition characteristics are significantly affected by the asphalt mixture conditions near the surface, thus proper design of the saturation level close to the surface has the potential to reduce drastically the ignitability of asphalt.

The present experiments are preliminary in nature; nevertheless the observations indicate the importance of addressing asphalt when defining the fire loads within a tunnel. Furthermore, they open an important research question that still remains unanswered: what are the properties that need to be established to develop a fire-safe asphalt mixture? Small scale experiments of the nature of the present tests could provide important clues in this matter.

Further details of this research will be published in **Tunnel Management International** in June 2006.

6. ACKNOWLEDGEMENTS

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